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INTRODUCTION TO THE ISSUE OF HYPOXIA IN THE GULF OF MEXICO

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In recent years there has been a growing concern about a large area of oxygen-depleted waters that develops seasonally in the Gulf of Mexico near the mouth of the Mississippi River. The size of the oxygen-depleted area varies from year-to-year and has extended from the mouth of the Mississippi River west to near the Texas border. Oxygen depletion in the nearshore Gulf can exceed 6,000 square miles in size and may form as early as February and last as late as October with the most widespread and persistent conditions occurring from Mid-May to Mid-September.

The area of oxygen depletion is called "hypoxia" or "hypoxic waters" which refers to waters with dissolved oxygen concentrations of less than 2 parts per million (mg L^{-1}). Two parts per million dissolved oxygen is generally accepted as the limit for most aquatic life survival and reproduction. Such oxygen-depleted bottom waters in shallow coastal and estuarine areas are found worldwide and their occurrence appears to be increasing, apparently accelerated by human activity (Diaz and Rosenberg 1996). In recent years, however, the hypoxic region in the northern Gulf of Mexico represents one of the largest zones of oxygen-deficient bottom waters in the western Atlantic Ocean. The areal extent of the hypoxic zone is greater than that of Chesapeake Bay and, in recent years, has rivaled hypoxic regions of the Baltic and Black Seas (Rabalais 1996).

Coastal eutrophication commonly results from nutrient inputs from diffuse sources, thus effects are not easily seen as connected to causes (Boesch 1996). However, presently available research has shown a relationship between Mississippi River flow, riverborne nutrients, plankton (algal) productivity, and bottom water hypoxia in the Gulf of Mexico. This paper provides a brief introduction to the issue of hypoxia in the Gulf of Mexico. This information is intended to be used as a starting point for discussion of the role of agriculture in the Upper Mississippi watershed as a source of nutrients and of the proper response from the agriculture and research community in what will likely be a concerted national effort to address the hypoxia problem.

Development of Hypoxia

Freshwater discharge from the Mississippi and Atchafalaya rivers forms the Louisiana Coastal Current which flows, on average, westward along the Louisiana coast and then southward along the Texas coast (Wiseman et al. 1996). This freshwater is of much lower salinity and is less dense than the heavy, saltier coastal shelf waters into which it flows. This density difference sets up a stratification in the water column, with the freshwater "riding" on top of the salt water. This stratification restricts the vertical mixing of the water column.

Primary production (algal and plant growth) in estuaries and nearshore coastal waters is generally limited by the availability of nitrogen. As a result, any increase in the inputs of dissolved inorganic nitrogen will likely increase primary production in coastal waters. Nutrient concentrations and loadings from the Mississippi River watershed have changed dramatically this century and have accelerated since the 1950's (Goolsby and Battaglin 1996). Concentrations of dissolved nitrogen and phosphorus have doubled, and silica have decreased by 50%. The result has been a large increase in the growth of phytoplankton (free floating algae) (Rabalais 1996). These changes have also resulted in a shift of the dominant phytoplankton, from diatoms which have a high demand for silica, to other diatom and non-diatom species. As the resulting massive phytoplankton blooms decompose, the cells sink to the bottom and utilize.

The hypoxia in the Gulf of Mexico is believed due to both the effects of stratification of the fresh and marine waters that restricts vertical reoxygenation of bottom waters and the oxygen-consuming breakdown of organic material mostly derived from river stimulated phytoplankton.

History and Distribution of Hypoxia in the Gulf of Mexico

Systematic surveys of the distribution of dissolved oxygen within the Gulf only began in 1985. Extensive distribution of hypoxia was found each summer since then, with the exception of 1988 (a record low flow year for mid-summer) (Rabalais 1996). Prior to 1985, the occurrence of hypoxia in the Gulf has only been assessed using information that was collected as a portion of other studies. Thus these surveys do not form a complete survey. For example, hypoxia in the Gulf was recorded in the early 1970's as part of environmental assessments of oil production and transportation development studies. Prior to the 1970's there is some anecdotal information from shrimp trawlers in the 1950s - 1960s of low or no catches, of "dead" or "red" water, but no systematic analysis of these records (Rabalais 1996).

Scientists studying the distribution of bottom-dwelling invertebrates have found evidence of an increase in oxygen deficiency stress since early this century, with a dramatic increase since the 1940s-1950s (Rabalais et al, 1996, Sen Gupta et al. 1996). These researchers collected and dated cores of the bottom sediment and looked at the trends of the dominant invertebrates by depth. Their evidence points to a progressive overall rise in oxygen stress based on a decrease in species not tolerant of oxygen stress, and an increase in species tolerant of low oxygen stress in the more recent sediments.

Areal Distribution and Seasonal Pattern

Prior to 1993, the average areal extent of bottom water hypoxia in mid-summer was 3,000 to 3,500 mi² (Rabalais et al. 1994). Distribution maps of mid-summer bottom water hypoxia since 1985 often show patchy areas of low oxygen downfield of each of the river deltas. Other distributions are continuous from the Mississippi River delta to the upper Texas coast. In those areas not below 2 mg L⁻¹, the dissolved oxygen concentration is still usually below 4 mg L⁻¹ and mostly below 3 mg L⁻¹ (Rabalais 1996). In 1993, in response to the "Great Summer Flood", the size of the hypoxic zone in the Gulf of Mexico doubled with respect to the 1985-1992 mid-summer averages and has remained large in subsequent years. The areal extent of this zone

during mid-summer surveys of 1993-1995 (approx. 6,000 mi² to 7,000 mi²) rivals the largest hypoxic areas elsewhere in the world's coastal waters.

Critically low dissolved oxygen concentrations occur in the lower water column from as early as late February through early October and nearly continuously from mid May through mid-September (Rabalais 1996). The stratification of the water column is very important in defining this distribution (Wiseman et al. 1996). Hypoxia is most widespread, persistent, and severe in June - August. The breakdown of the stratification by winds from either tropical storm activity or passage of cold fronts determines the persistence of hypoxia into September and October. Hypoxia is not just a bottom-hugging lens of water but may encompass from 10% to 80% of the total water column, depending on the depth of the water (Rabalais 1996).

Effects on Living Resources

The presence of hypoxic waters in an area can be expected to have a variety of impacts to the aquatic community (Hanifen et al. 1996). Free-swimming communities will move away from areas with insufficient dissolved oxygen and congregate along the borders of the hypoxic area until conditions are conducive to their return. Mobile organisms that live on top of the sediments similarly will leave the area if possible. Planktonic communities that are unable to swim away from a hypoxic water mass, or communities associated with specific water bottoms, would be subject to stress and/or mortality depending on their length of exposure to hypoxia. Persistently oxygen stressed bottom communities are characterized as having only a few tolerant species with low biomass and a limited ability to recover following abatement of oxygen stress (Rabalais 1996).

While preliminary indications are that fisheries communities associated with the water column have not yet been effected, the State of Louisiana is concerned about the long term implications of hypoxia on their one-half billion dollar a year fisheries resource (Hanifen et al. 1996). Potential impacts include a redistribution of highly mobile species; a concentrating of fishing effort resulting in increased harvest; low catch rates in directed fisheries; localized overfishing; direct mortality; and decreased reproduction due to impacts on the food base. Such changes in the distribution and abundance of fish species could result in a loss of commercial and recreational harvest opportunities and a net economic loss to the region.

The Role of Upper Mississippi River Watershed Inputs

Monitoring by the United States Geological Survey has identified that the principal areas contributing nutrients to the Mississippi River and ultimately the Gulf of Mexico are streams draining the corn belt states, particularly Iowa, Illinois, Indiana, Ohio, and southern Minnesota (Goolsby and Battaglin 1996). They estimate that about 60% of the nitrate transported by the Mississippi River is derived from less than 20% of the basin. Current sources of nitrogen identified for the Mississippi River basin, in decreasing order of their input include commercial fertilizers, animal manures, legumes, municipal and domestic wastes, and atmospheric deposition. Nitrogen fertilizer is estimated to account for more than one-half of the annual nitrogen input.

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